RAI Volume 2, Chapter 2.1.1.6, Second Set, Number 3:

> Explain the development of cut sets used to demonstrate that the double interlock preaction fire-protection system will satisfy the nuclear safety design bases set forth in SAR Table 1.4.3-2. Specifically,
>
> - Explain why alternate event sequences, such as, false fire detection by one of the interlocked fire/smoke detectors was not included as a cut set to determine overall probability of spurious activation of the system and inadvertent introduction of water.
>
> - Justify a human error screening value of 0.025 in conjunction with the sprinkler head failure probability of 1.6×10^{-6}, to determine the overall spurious activation probability.
>
> The derivation of a failure probability for the double interlock preaction system was based on the failure probability of a sprinkler head and simultaneous failure of a solenoid valve as, described in the reliability and event sequence categorization analyses (e.g., BSC 2008a Section 6.2.2.9.1). It appears that there may be additional cut sets, not considered in the failure probability, that may lead to inadvertent introduction of water. For example, malfunction of a fire-detector may trip a solenoid valve, resulting in water discharge from a damaged sprinkler head.

1. RESPONSE

The fire protection system nuclear safety design basis probabilities set forth in SAR Table 1.4.3-2 are established based on the screening analysis provided in Section 6.2.2.9.1 of *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009). The analysis is bounding because it uses cut sets that overestimate those of a more detailed analysis, even though not all cut sets are represented. The results of the fault tree analysis provided in Attachment A demonstrate that the nuclear safety design basis probability values provided in SAR Table 1.4.3-2 are bounding. The nuclear safety design basis probabilities for spurious sprinkler actuation in a waste handling area in the Canister Receipt and Closure Facility (CRCF) and Wet Handling Facility (WHF) are 1×10^{-6} and 6×10^{-7}, respectively; a mean failure probability of 2×10^{-7} was calculated in the fault tree analysis in Attachment A.

1.1 SCREENING ANALYSIS RESULTS

The screening model in Section 6.2.2.9.1 of *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009) addressed cut sets involving failures or spurious actuation of the major components associated with spurious actuation of the fire protection system, including the solenoid valve and a sprinkler head, and a human failure event. Based on this screening analysis, nuclear safety design basis controlling parameters were developed to satisfy the safety function of maintaining moderator control in areas where there is a potential for canister breach. These nuclear safety design basis parameters are presented for the fire protection systems for the CRCF and WHF in SAR Tables 1.9-3 and 1.9-4, respectively.

As discussed during the NRC clarification call on July 16, 2009, a fault tree analysis has been completed to examine a failure of the fire-suppression system in more detail and document the demonstration of conservatism previously mentioned. The fault tree examines an inadvertent actuation of the fire-suppression system in the CRCF and WHF in areas to which the nuclear safety design basis reliability requirements against inadvertent introduction of fire suppression water apply. The fault tree analysis, provided in Attachment A, includes component failures (i.e., flame detector, solenoid valve) and human errors that could contribute to the fault tree top event; namely, "Inadvertent Fire Suppression System Actuation Leading to an Important To Criticality End State." The results of this analysis, which include the types of failures described in this RAI, are bounded by the values calculated in the screening analysis, as well as the controlling parameters reported in SAR Tables 1.9-3 and 1.9-4.

1.2 HUMAN ERROR SCREENING VALUE

The human error screening value of 0.025 used in the screening analysis is derived from the human failure event analysis presented in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009, Appendix E.III, Table E.III-2), which presents screening values and qualitative descriptions for probabilities of various human failure events. The qualitative descriptions of the human failure event probability values are provided to help calibrate a human failure event assessment by providing specific examples that fall into the specific categories and probabilities of human failure events (e.g., likely to fail, 0.5; infrequently fails, 0.1; unlikely to fail, 0.01, highly unlikely to fail, 0.001). The human failure event probability considered in the cut set that includes a human error screening value of 0.025 denotes a human failure that leads to water being left in dry piping after the last test (in the first quarter following the annual test). This human failure event probability is similar to the preinitiator human failure event probabilities of "failure to properly restore an operating system to service when the degraded state is not easily detectable" (screening value is 0.01) and the human-induced initiator human failure events of "failure to properly restore an operating system to service when the degraded state is easily detectable" (screening value is 0.001), and "failure to properly conduct an operation performed on a very regular basis (on the order of once/week)" (screening value is 0.01) (BSC 2009, Appendix E.III, Table E.III-2). Based on these similar human failure event probabilities, a value of 0.025 was selected to represent a mean value that would result from considering uncertainties because the screening analysis uses point estimates only. The analysis in Attachment A does not use a point estimate for this value; instead a median value of 0.01 with an error factor of 10 is used.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2007. *Canister Receipt and Closure Facility 1 Fire Hazard Analysis*. 060-M0A-FP00-00100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071129.0032.

BSC 2009. *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis*. 060-PSA-CR00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20090112.0004.

Denson, W.; Chandler, G.; Crowell, W.; Clark, A.; and Jaworski, P. 1994. *Nonelectronic Parts Reliability Data 1995*. NPRD-95. Rome, New York: Reliability Analysis Center. TIC: 259757.

Attachment A

This attachment presents the results of a fault tree analysis of an inadvertent actuation of the CRCF and WHF automatic, double-interlocked preaction sprinkler system such that an important to criticality event sequence end state may occur. This analysis develops the conditional probability of inadvertent fire suppression system actuation given that a canister has been breached. As with the screening analysis presented in Section 6.2.2.9.1 of *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009), a 30-day (720 hr) period is the mission time.

A.1 Double Interlock Preaction Fire Suppression System Description

The coverage areas of automatic double-interlocked preaction sprinklers protect areas of the CRCF and WHF where waste forms are handled, areas where there is a potential for a canister breach, and areas where water-sensitive electrical or important to safety structures, systems, or components are located. The double-interlocked preaction sprinkler systems operate automatically upon receipt of two separate inputs, in any order. A signal must be sent to open the solenoid valve based on inputs from the fire detector or fire detectors array, allowing water to flow to the sprinkler heads. The flame detectors, which actuate a preaction sprinkler system, are located in areas where important to safety structures, systems, or components are located (BSC 2007). The second action is the opening of the sprinkler head fusible links, allowing air to escape from the sprinkler piping between the check valve and the sprinkler head, which allows the check valve to open and water to flow through the sprinkler heads. Periodic surveillances ensure the continued capability of the double-interlocked preaction sprinkler systems.

A.2 Fault Tree Model

The fault tree developed in this attachment follows the same method presented in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009, Attachment B), including use of the SAPHIRE fault tree analysis software. The fault tree is applicable only to those areas in the CRCF and WHF to which the nuclear safety design basis reliability requirements against inadvertent introduction of fire suppression water apply, namely, areas in which a canister or cask may be breached.

The fault tree developed in this analysis, titled “Fire-Suppression,” is presented in Figure A-1. The top event in this fault tree is “Inadvertent fire suppression system actuation leading to an important to criticality end state.” The fault tree includes events (electro-mechanical control failures and human actions) that can initiate an inadvertent actuation of the fire suppression system in a waste handling area.

A.3 Basic Event Data

Table A-1 contains a list of basic events and basic event input data used in the “Fire-Suppression” fault tree. Included are the human failure events identified in Section A.4.

A.3.1 Probability of Fire Suppression System Water Entering a Canister

Spent nuclear fuel is always contained in canisters within an overpack in the CRCF and, except for uncanistered transportation casks, in the WHF. These overpacks include transportation casks, shielded transport casks, aging overpacks, and waste packages. Impacts that breach a canister within an overpack will not cause breach of the overpack. The overpacks holding the canisters are elevated above the floor when in a railcar, truck, canister transfer trolley, site transporter, or waste package transfer trolley. The waste package is elevated above the floor when it resides inside the transport and emplacement vehicle (TEV). However, there are no Category 1 or 2 event sequences associated with canister breach within the TEV. A lifted canister or cask increases the canister elevation above the floor. Therefore, water from the fire suppression system is unlikely to attain a depth that would contact overpacks or canisters. Furthermore, unbreached overpacks (except aging overpacks) will not allow water to contact a canister within. Although aging overpacks are vented, there are no Category 1 or 2 event sequences involving breach of a canister within an aging overpack on a site transporter. Therefore, for water to enter an overpack and contact a breached canister, it must enter from sprinkler heads located above an overpack containing a canister.

In the WHF, dual purpose canisters (DPCs) are cut open and transportation casks containing uncanistered spent nuclear fuel are opened. These canisters are filled with borated water such that event sequences leading to an “Important to Criticality” end state can not be obtained. Similarly, fuel assemblies within TADs that are not yet welded are immersed in borated water. The situation of interest, therefore, arises for canistered fuel in overpacks in the CRCF and WHF before they are cut open or after they are sealed and evacuated.

The areas of the CRCF and WHF where waste forms are handled (i.e., areas where there is a potential for a canister breach) are serviced by automatic double-interlocked preaction sprinklers. The canisters in these areas are shielded during facility operations by cask preparation platforms, concrete floors and walls, the canister transfer machine shield bell or shield skirt, the waste package transfer trolley, the canister transfer trolley, slide doors, or the shield compartment of the TEV. The sprinkler heads are located above the structures, equipment, and components (e.g., trolleys, platforms) in these areas. Unborated water must actually enter the canister to be important to criticality. Water released from a sprinkler head could be potentially blocked from entering an open overpack holding a breached canister by these structures, equipment, and components. The water would have to directly spray onto the top of an open overpack and enter the overpack via the gap between the canister wall and overpack inner wall (typically a gap of one-half an inch). Furthermore, a canister in a dropped overpack typically breaches at or near the bottom of the canister; therefore, there would be a small leak path through which water from a sprinkler head could potentially enter the canister. Much of the water entering the gap would evaporate because of the elevated temperature.

Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis (BSC 2009, Section 6.2.2.9.1) states that the estimated number of sprinklers to be located in areas where waste forms are handled is one sprinkler per 130 square feet. In the fault tree analysis, therefore, a conservative estimate of the number of sprinkler heads whose spray could reach a breached canister is five. This estimate is conservative within canister unloading rooms and waste package positioning rooms because of the size of these rooms and the aforementioned potential of equipment to interfere with the spray reaching the inside of an overpack.

The basic event titled “WATER-ENTERS-CANISTER” (fire suppression water entering a breached canister) is assigned a mean failure probability of 1×10^{-3}. This failure probability is assigned using the criterion that such an event is “highly unlikely” (BSC 2009, Section E.III).

Table A-1. Basic Event Probability Data Used in the Fire-Suppression Fault Tree Analysis

Name	Description	Calculation Type[a]	Calculated Probability	Mean Failure Probability	Lambda	Mission Time	Error Factor	Source/Basis
AIR-RECEIVER-FAILS	Air supply system fails to deliver air	3	4.3×10^{-4}	–	6.0×10^{-7}	720	10	Hourly failure air receiver failure rate to supply air of 6.0×10^{-7} was obtained from Table C4-1 in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009).
WATER-INTO-CANISTER	Water enters a breached canister	1	1.0×10^{-3}	1.0×10^{-3}	–	–	10	See discussion in Section A.3.1.
FLAME-DETECTOR-FAILS	Flame detector sends spurious signal	1	4.4×10^{-7}	4.4×10^{-7}	–	–	5	Detector (fire) failure probability of 4.4×10^{-7} was obtained from *Nonelectronic Parts Reliability Data 1995* (Denson et al. 1994). An error factor of 5 was selected as appropriate for this value.
SOLENOID-VALVE-LEAK	Solenoid valve leaks, allowing water to enter discharge pipe	3	3.4×10^{-2}	–	4.9×10^{-5}	720	17	Hourly solenoid valve failure rate of 4.9×10^{-5} was obtained from Table C4-1 in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009).
SOLENOID-VALVE-OPENS	Solenoid valve spuriously opens	3	2.9×10^{-4}	–	4.1×10^{-7}	720	3	Hourly solenoid valve spurious operation rate of 4.1×10^{-7} was obtained from Table C4-1 in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009).

Name	Description	Calculation Type[a]	Calculated Probability	Mean Failure Probability	Lambda	Mission Time	Error Factor	Source/Basis
SPRINKLER-HEAD-BREAK	Human error results in breakage of sprinkler head	1	2.7×10^{-3}	2.7×10^{-3}	–	–	10	A human failure event probability of 0.001 was selected for the probability of a sprinkler head breakage due to human error. This value was chosen as representing a “highly unlikely” to fail event, as discussed in Appendix E.III of *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009). The 0.001 median value equates to a mean value of 2.7×10^{-3}; an error factor of 10 was selected as appropriate for this probability.
SPRINKLER-HEAD-FAIL	Sprinkler head fusible link fails, opening flow path	3	2.2×10^{-3}	–	3.1×10^{-6}	720	3	Hourly sprinkler failure rate of 6.2×10^{-7} per head was obtained from *Nonelectronic Parts Reliability Data 1995* (Denson et al. 1994). An error factor of 3 was selected as appropriate for this value. As described in Section A.3.1, this rate was conservatively multiplied by 5 to account for spray from up to 5 heads contacting a container holding a breached canister.
WATER-LEFT-IN-PIPE	Human error leaves water in pipe	1	2.7×10^{-2}	2.7×10^{-2}	–	–	10	A human failure event probability of 0.01 was selected for the probability of water being inadvertently left in a discharge pipe following annual testing. The 0.01 value represents a “failure to properly restore an operating system to service when the degraded state is not easily detectable,” as discussed in Table E.III-2 in Appendix E.III of *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009). The 0.01 median value equates to a mean value of 2.7×10^{-2}; an error factor of 10 was selected as appropriate for this probability.

NOTE: [a] The relevant SAPHIRE calculation types are as follows: (1) For failure on demand, the value specified is used directly as the basic event mean failure probability. (3) For an operating component without repair in nondemand failure mode, the basic event mean failure probability is calculated as $P = 1 - \exp(-L \times t_m)$, where L is the hourly failure rate and t_m is the mission time in hours. The number shown in the “Mean Failure Probability” column is actually a point estimate, which approximates the mean.

A.4 Human Failure Events

Two human failure events are associated with human error. The event titled “sprinkler-head-break” addresses operator-induced breakage of a sprinkler head in a waste processing area. The event titled “water-left-in-pipe” addresses water being inadvertently left in a discharge pipe following annual testing of the fire suppression system.

A.5 Common-Cause Failures

No common-cause failures apply to the fault tree developed in this analysis.

A.6 Uncertainty and Cut Set Generation Results

Table A-2 contains the uncertainty results obtained for the “Fire-Suppression” fault tree using a cutoff probability of 1×10^{-15}. Table A-3 provides the cut set generation results for this fault tree.

Table A-2. Uncertainty Results of the “Fire Suppression” Fault Tree

Uncertainty Results	
Name	**FIRE-SUPPRESSION**
Random Seed 1234	Events 8
Sample Size 1000	Cutsets 8
Point Estimate	1×10^{-7}
Mean Value	2×10^{-7}
5th Percentile Value	5×10^{-10}
Median Value	1×10^{-8}
95th Percentile Value	4×10^{-7}
Minimum Sample Value	1×10^{-11}
Maximum Sample Value	1×10^{-4}
Standard Deviation	2×10^{-6}
Skewness	5×10^{1}
Kurtosis	4×10^{3}

Table A-3. Cut Set Generation Results of the “Fire Suppression” Fault Tree

Cut Set Generation Results		
Name:		**FIRE-SUPPRESSION**
Cut Size	#	minCut
1	0	—
2	0	—
3	6	1×10^{-7}
4	2	7×10^{-11}
5	0	—
6	0	—
7	0	—
8	0	—
9	0	—
10	0	—
>10	0	—
Total	8	1×10^{-7}

A.7 Cut Sets

Table A-4 contains the cut sets for “Fire Suppression” fault tree.

Table A-4. Cut Sets for the "Fire-Suppression" Fault Tree

Cut Set Number	% Total	% Cut Set	Probability/ Frequency	Basic Event	Description	Event Probability
1	54	54	7.1×10^{-8}	SPRINKLER-HEAD-BREAK	Human error breaks sprinkler head off	2.7×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
				WATER-LEFT-IN-PIPE	Human error leaves water in pipe	2.7×10^{-2}
2	99	45	5.9×10^{-8}	SPRINKLER-HEAD-FAIL	Sprinkler head fusible link fails, opening flow path	2.2×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
				WATER-LEFT-IN-PIPE	Human error leaves water in pipe	2.7×10^{-2}
3	99	0.6	7.8×10^{-10}	SOLENOID-VALVE-OPENS	Solenoid valve spuriously opens	2.9×10^{-4}
				SPRINKLER-HEAD-BREAK	Human error breaks sprinkler head off	2.7×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
4	100	0.5	6.6×10^{-10}	SOLENOID-VALVE-OPENS	Solenoid valve spuriously opens	2.9×10^{-4}
				SPRINKLER-HEAD-FAIL	Sprinkler head fusible link fails, opening flow path	2.2×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
5	100	0.0	4.0×10^{-11}	AIR-RECEIVER-FAILS	Air supply system fails to deliver air	4.3×10^{-4}
				SOLENOID-VALVE-LEAK	Solenoid valve leaks allowing water to enter discharge pipe	3.4×10^{-2}
				SPRINKLER-HEAD-BREAK	Human error breaks sprinkler head off	2.7×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
6	100	0.0	3.3×10^{-11}	AIR-RECEIVER-FAILS	Air supply system fails to deliver air	4.3×10^{-4}
				SOLENOID-VALVE-LEAK	Solenoid valve leaks allowing water to enter discharge pipe	3.4×10^{-2}
				SPRINKLER-HEAD-FAIL	Sprinkler head fusible link fails, opening flow path	2.2×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
7	100	0.0	1.2×10^{-12}	FLAME-DETECTOR-FAILS	Flame detector sends spurious signal	4.4×10^{-7}
				SPRINKLER-HEAD-BREAK	Human error breaks sprinkler head off	2.7×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}
8	100	0.0	9.9×10^{-13}	FLAME-DETECTOR-FAILS	Flame detector sends spurious signal	4.4×10^{-7}
				SPRINKLER-HEAD-FAIL	Sprinkler head fusible link fails, opening flow path	2.2×10^{-3}
				WATER-INTO-CANISTER	Water enters a breached canister	1.0×10^{-3}

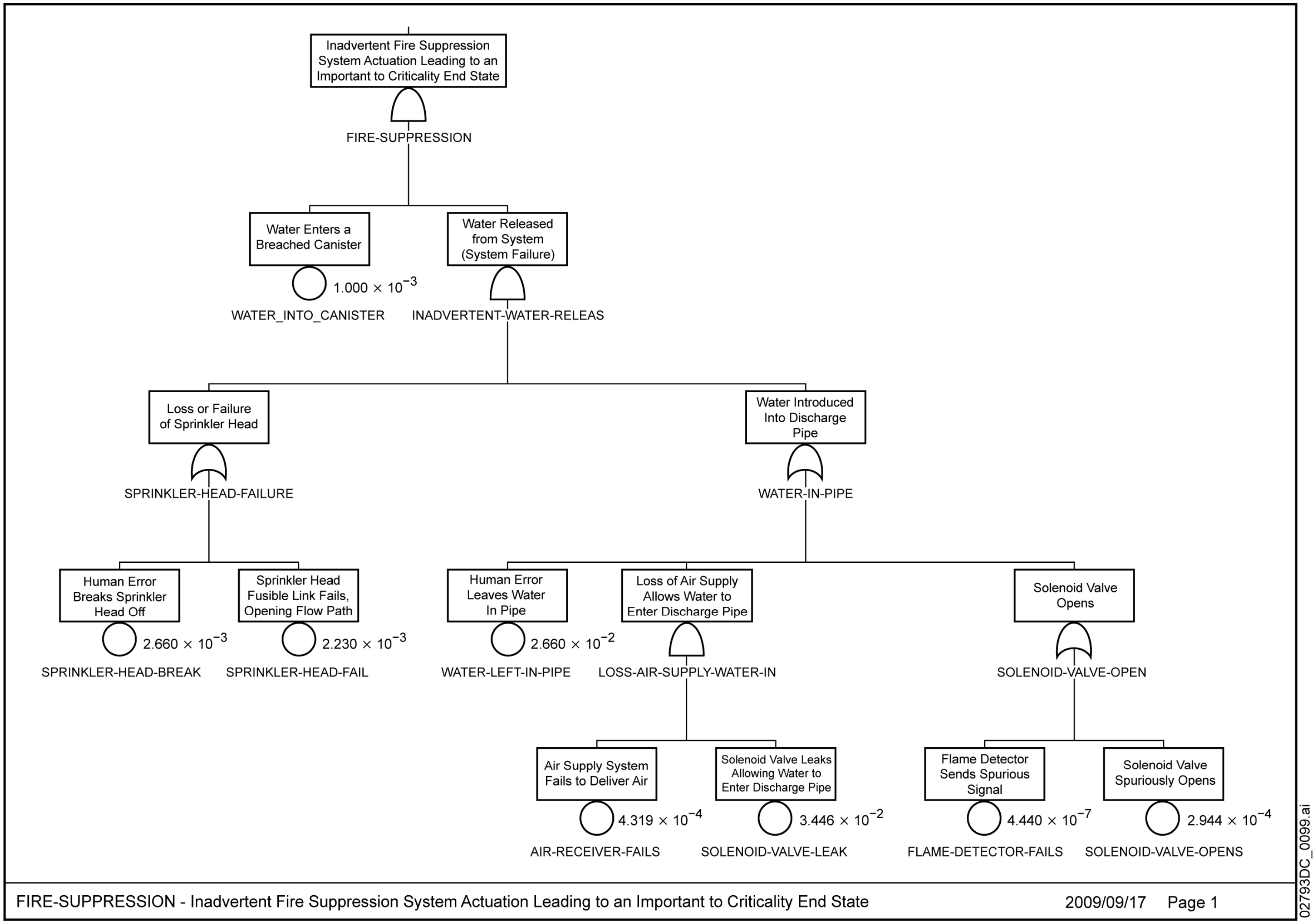

Figure A-1. Fault Tree FIRE-SUPPRESSION

A.8 Results

The results of this analysis are presented in Table A-5. The mean probability value for the top event of the fault tree was calculated to be 2×10^{-7}. This result applies to both the CRCF and WHF. The top cut set includes the two identified human failure events as well as the probability of water entering a breached canister basic event.

The fault tree analysis results demonstrate that the results calculated with the inclusion of additional component failures and human failure events are bounded by the screening analysis presented in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009, Section 6.2.2.9.1) in that the screening probabilities exceed the 95th quantile of the results of the more detailed analysis. The nuclear safety design basis controlling parameter probabilities are also bounded by the screening analysis probabilities (reported in SAR Tables 1.9-3 and 1.9-4). The fault tree analysis demonstrates that the addition of components (e.g., the solenoid valve, flame detector, air supply system) did not produce a mean or 95th quantile failure probability for the top event that was greater than the results obtained from the screening analysis. The results from the screening analysis are, therefore, bounding.

It should be noted that separate screening analysis values were reported for the CRCF and WHF because these values are obtained from the screening analysis calculations that used as input the approximate number of sprinkler heads specific to the waste handling areas of these facilities. The inputs used in the fault tree analysis include all-modes failure rates obtained from *Nonelectronic Parts Reliability Data 1995* (Denson et al. 1994), which offer an additional layer of conservatism.

Table A-5. Probability of Spurious Sprinkler Actuation Leading to an Important to Criticality End State

Mean Probability of Fire Suppression System Inadvertent Actuation Leading to an Important to Criticality End State	**Screening Analysis/NSDB Probability of System Actuation in Waste Handling Area (CRCF)**	**Screening Analysis/NSDB Probability of System Actuation in Waste Handling Area (WHF)**
2×10^{-7}	1×10^{-6}[a]	6×10^{-7}[b]

NOTE: [a] SAR Table 1.9-3
[b] SAR Table 1.9-4

NSDB = nuclear safety design bases